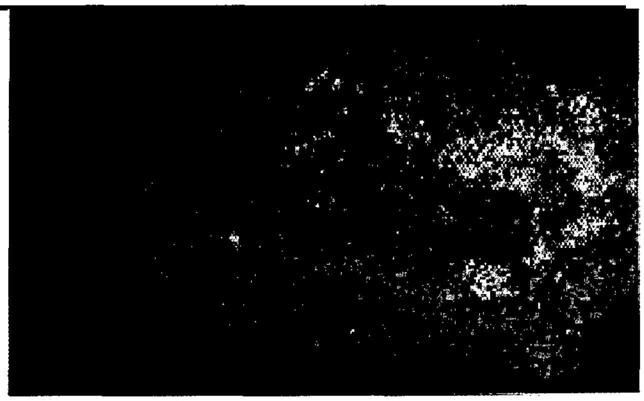
2nd International Workshop

ROCKET COMBUSTION MODELING



TEST CASE RCM-3

Mascotte single injector

- 60 bar -

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DLR, Lampoldshausen

French-German Research on Liquid Rocket Combustion

I- GENERAL PRESENTATION

The MASCOTTE cryogenic combustion test facility was developed by ONERA to study fundamental processes which are involved in the combustion of cryogenic propellants, namely liquid oxygen (LOX) and gaseous hydrogen (GH2). Three versions of this test facility have been built since the project was started in 1991. The first tests at atmospheric pressure were performed in January 1994, while pressures up to 10 bar were achieved in fall 1995.

A number of additional test data has been recently obtained at chamber pressure of 60 to 70 bar, which is higher than the critical pressure for LOX (50,4 bar). This range of pressure is thought to be representative of the chamber pressure encountered in a real engine like the Ariane 5 Vulcain Engine. Due to the difficulties met in running those high pressure experiments, the data base is smaller than for the 10 bar case, but some experiments will soon provide more data.

Test case RCM3 will thus consist of modeling the MASCOTTE combustor at a chamber pressure of 60 bar. The details for both the test facility geometry and the operating conditions required for the numerical simulations are listed below.

II- GEOMETRY

a) Test combustor

The MASCOTTE test combustor has a square section of 50 mm x 50 mm (Figure 1).

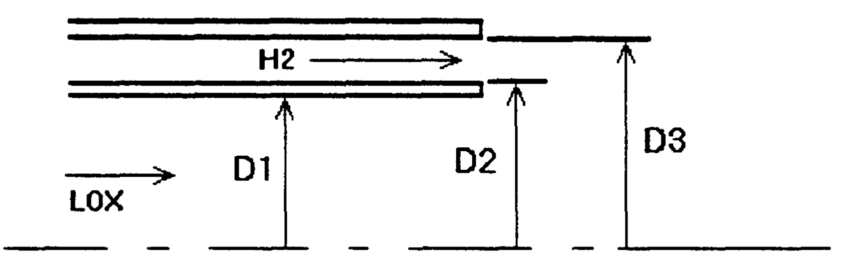
The injector head consists of a single coaxial injector element.

Combustion is initiated by using an H2/O2 igniter (O/F = 4) for roughly 2 seconds.

Figure 2 summarizes the geometry of the combustion chamber used for tests at 10 bar . The black dots indicate the locations of wall temperature transducers.

b) Injector

The MASCOTTE injector is a coaxial element consisting of a core of liquid oxygen surrounded by a high speed flow of gaseous hydrogen to provide good atomization properties.



The dimensions of the injector are listed below.

	D1	D2	D3
DIAMETER	5.0 mm	5.6 mm	10.0 mm

Figure 3 shows a sketch of injector head geometry.

III- TEST OPERATING CONDITIONS

a) Operating point

The operating point chosen for this test case is a 60 bar case, called A-60 case. The operating conditions are defined in the following table:

PRESSURE	O/F	$\dot{m}$ (LOX)	$\dot{m}$ (H2)
60 bar	1.4	100 g/s	70 g/s

b) Propellants

Oxygen is injected under liquid conditions at 85 K, while hydrogen is injected under gaseous conditions at a temperature of approximately 287 K.

The physical properties of the propellants are summarized below:

Conditions	H2	O2
Pressure	6 MPa	6 MPa
Massflow	70 g/s	100 g/s
Temperature	287 K	85 K
Density	5.51 kg/m^3	1177.8 kg/m^3
C_p	15110 J/kg/K	1660.9 J/kg/K
Velocity	236 m/s	4.35 m/s
Viscosity	8.67E-4 kg/m/s	2.34E-4 kg/m/s
Surface tension	-	Cf § 4.

c) Turbulence

No data are yet available regarding the turbulence level at the injector exit. However, in order to make the comparison between various computations easier, we propose fixing the kinetic energy level at $\iota = 5\ \%$ ($\iota^2 = 2/3\ k\ /\ U^2_{inj}$). In addition, we recommend deriving the value of turbulence dissipation ε at the inlet using a turbulence length of 4 mm as a representative scale of the GH2 injection ring. The length of the GH2 inlet duct can be chosen by the participant, as well as the wall boundary condition. It is preferred to have fully developed velocity and turbulence profiles.

IV- GENERAL DATA FOR COMPUTATIONS

The list below describes the methods which should be used for this simulation.

- Computational Domain

  - A computation of the entire chamber (i.e., including the nozzle) is preferred. The nozzle, if any, will be chosen in order to have 60 bar static chamber pressure.

  - If there are problems, computations may be performed for a shorter chamber (without the nozzle) with the following characteristics:

    - Chamber length = 400 mm

    - Exit boundary condition: Constant pressure, p = 60 bar

- Droplet Injection

Given the lack of data in this pressure range, which is above the theoretical critical pressure for LOX, a rather simple representation will be chosen for LOX injection conditions.

  - Droplet size distribution:

    - One droplet size: D32 = 50 micron, initial velocity of drops, Vinj = 4.35 m/s

    - The droplets will be injected in the axial direction, with a uniform mass flow on the LOX post exit area.

- Physical Models

  - Combustion, turbulence, and evaporation models (also treatment of surface tension) are not specified. Participants are free to choose these models as they see fit.

V- FREE CASE

Given the physical uncertainties concerning the presence of LOX droplets in this pressure range, an additional case will be calculated with no specifications concerning the conditions of LOX injection (for example, eulerian atomisation model or real gas model can be used instead of a lagrangian description) .

VI- EXAMPLES OF AVAILABLE DATA

Each test run performed on MASCOTTE provides a set of standard temporal data, such as propellant mass flow rate, pressures, wall temperatures, and propellant temperature at the inlet.

As of today, only one test campaign is available for test data at 60 bar chamber pressure: OH emission (figure 4 a)). Abel transform of the shots were performed in order to have an axisymetrical view of the flame (figure 4 b)). Other diagnostics are currently under investigation but the data is not yet available.

VI- REQUESTED RESULTS

Despite of the few information available at 60 bar, the results of numerical computations must be presented in such a way that they can be compared to future experimental data, and to calculations performed in the same combustor at 10 bar. The participants are requested to provide the following information (to the extent possible depending on the output of the numerical code):

- Radial profiles of mean temperature and standard deviation at CARS measurement locations (x/D1 = 10; 20; 30; 40; 50; 60). x represents the axial distance from the injector exit (see Figure 2), D1 = 5 mm.

- Mean temperature as a function of distance from the injector at three radial locations (y/D1 = 1; 2; 3).

- OH mass fraction contours in the near field of the injector (up to 150 mm downstream); see Fig. 4.

- Gaseous oxygen contours in the near field of the injector (up to 150 mm downstream).

- Axial profile of mean wall temperature (adiabatic wall temperature).

VII- REFERENCES

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[3] Herding. G, Snyder. R, Scouflaire. P, Rolon. C and Candel. S, "Emission and Laser Induced Fluorescence Imaging of Cryogenic Propellant Combustion", *Conference on Propulsive Flows in Space Transportation Systems*", (Bordeaux, France), pp 1-14, 1995.

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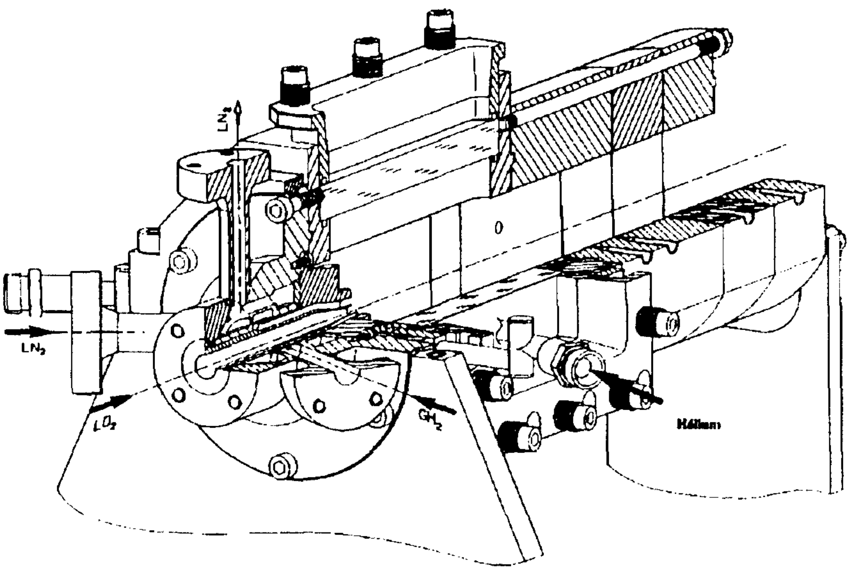

Figure 1: MASCOTTE Combustor

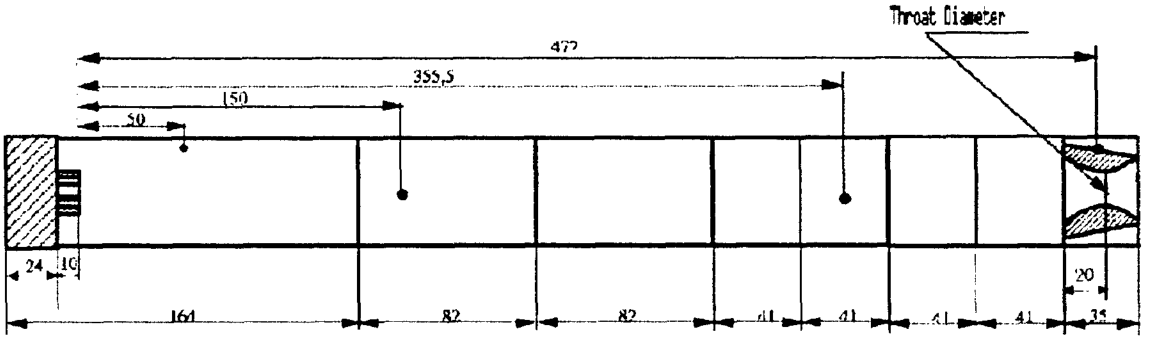

Figure 2: Combustor geometry (in mm): Throat diameter is **9 mm** for the 60 bar case

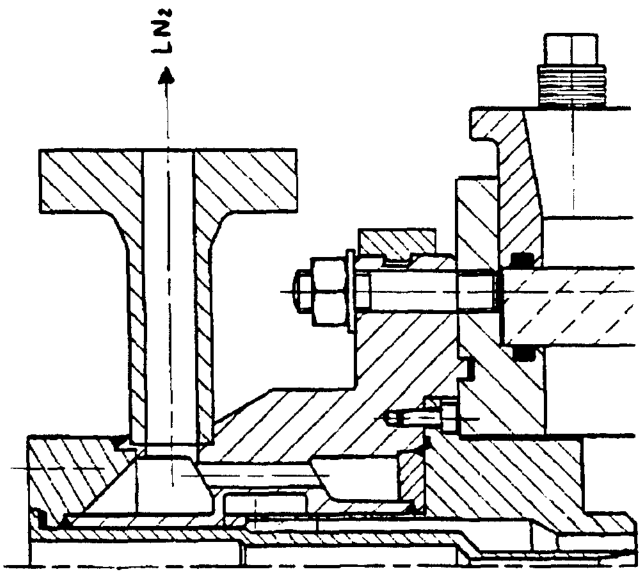

Figure 3: Injector head

(a)

(b)

Fig. 4: Average emission image a) and Abel-transformed emission image b) for operating point A-60, p = 60 bar.